Tunable Resonance of Star Shaped Nanostructures

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Abstract: Auto assembled Ag-ZnO [1] star shaped nanostructures depicted in figure 1, presents their natural electromagnetic resonance at 60 THz [2]. In this work we present that is possible changing this value by covering it with a variable in thickness layer of gold. The analysis is performed by numerical simulations using COMSOL Multiphysics®.

**Keywords:** COMSOL Multiphysics®, Nanoantennas, FEM simulation.

1. Introduction

Recent advances in nano fabrication, electron microscopy imaging and near field microscopy allowed metallic structures to be defined and characterized with sizes comparable or smaller to that of visible light, wavelengths of several hundred nanometers, opened up the possibility of apply nanotechnology and nanoscience in areas with pressing needs, e.g., in sensing, imaging, energy harvesting, and disease cure and prevention, have brought revolutionary improvements.

Metallic nanostructures can convert freely propagating electromagnetic radiation into localized energy, also can control and manipulate optical fields at the nanometer scale. Modifying the geometry and material of nanostructures is possible perform a strong coupling with the magnetic and/or electric component of an incident electromagnetic wave, in which the resonant frequency is dependent on the nanostructure size and shape.

In this work we present the electromagnetic analysis of star shaped nanostructures.

Auto assembled Ag-ZnO [1] star shaped nanostructures depicted in figure 1, presents their natural electromagnetic resonance at 60 THz [2]. Since star shaped geometry showed some interesting interactions with electromagnetic field in the optical regime, it is proposed in this work to adapt the geometry to perform some numerical studies assuming a possible subsequent fabrication by the method of nanolithography, a more convenient method to perform superficial nanoantennas which is the main (but not limited to it) application purpose as will be discussed later in this work. By covering the original auto assembled Ag-ZnO structure (fig. 1) with gold (Au), it is possible to change and adjust their electromagnetic field interaction allowing the purpose of having the directional-enhancer electric field nanostructure.
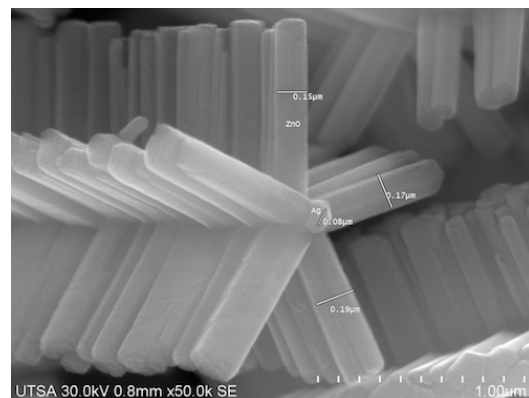
Figure 1. Star shaped nanostructure.

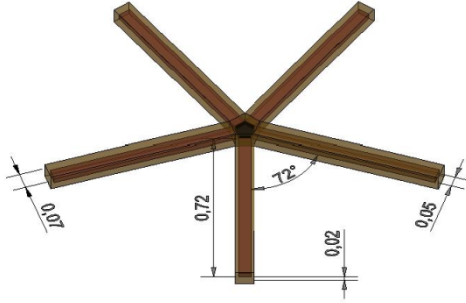## 1.1 Design parameters of nanostructure for numerical simulations

Figure 2. Design parameter.

Length of arms	0.72 μm
Angle	72°
Thickness	0.02 μm
Width of arms	0.07 μm

Table 1. Parameter of the star shaped nanostructures.

2. Computational Methods

Using the COMSOL's RF module [3] to solve equation 1, and applying a planar electromagnetic wave, we can find the interaction of electromagnetic field over the structure for different thickness layer of gold.

$$\nabla \times (\nabla \times E) - k_0{}^2 \varepsilon_r E = 0 \qquad (1)$$

Equation 1 is obtained by Faraday, Ampere equations and constitutive relations.

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad (2)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (3)$$

Using constitutive relations we get:

$$\nabla \times H = \sigma E + \frac{\partial \varepsilon E}{\partial t} \qquad (4)$$

$$\nabla \times E = -\mu \frac{\partial H}{\partial t} \qquad (5)$$

To perform the simulation, it was constructed a geometry using three different domains, one of them for the star shaped nanostructure, other for covering the nanostructure with air and used as a port to generate the electromagnetic field and applying the scattering boundary condition, and the last one used as a silicon or another material substrate, scattering boundary condition and where the nanostructure is supported or placed.

In order to have a better result we used tetrahedral mesh. Figure 3 shows the mesh of the structure.
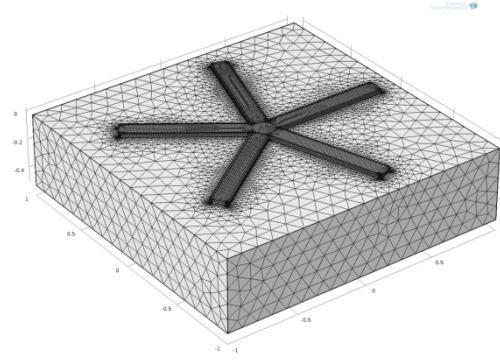

Figure 3. Mesh of the geometries

For each different thickness, must be necessary find their respective frequency of resonance where COMSOL's capabilities are so helpful allowing to perform complex, large and repetitive amount of calculations and presenting the results in a both, qualitative (3D images representing the behavior of electromagnetic field) and quantitative (data, tables and line graphs without any other postprocessing tools or software). For a particular case of a 50 nm of thickness, figure 4 depicts the shape and intensities in their resonance frequency and figure 5 depicts the electromagnetic field intensity response as a function of frequency. As geometry is varying, some other unique properties of COMSOL were used: "Geometry Import" and "LiveLink for Autocad".
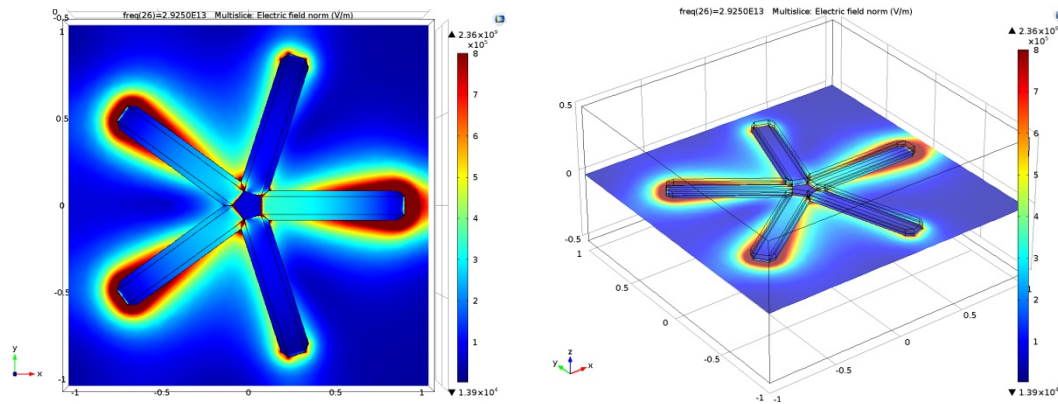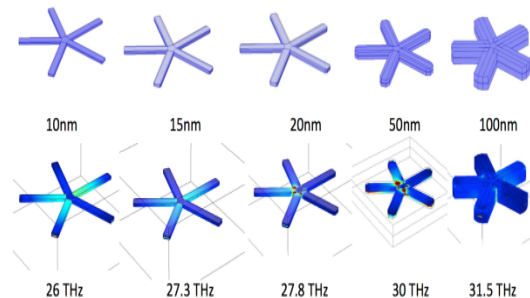
Figure 4. Electric field norm around the nanoantenna under resonant frequency condition for 50 nm of thickness.
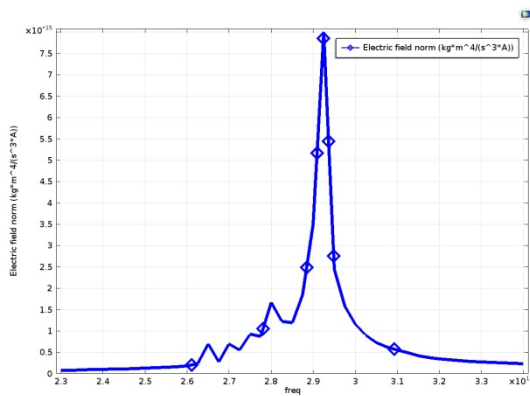
Figure 5. Freq. vs. Electric field norm.

The results show in figure 7 the curve of frequency vs. gold layer thickness is approximated to linear fitted curve.


Figure 6. Relation between gold layer thickness and their respective resonant frequency.

3. Results and discuss

Using COMSOL Multiphysics ® based in finite element method, numerical simulation was realized, getting like result the electric field distribution for star shaped nanostructures.

It is possible to have control about the resonance frequency over the star shaped Ag-ZnO nanostructures by covering them with a layer of gold. The resonance frequency is a function of the layer thickness as can be seen in figure 6 and figure 7. Figure 6 shows the electric field concentration of nanostructures and their respective resonance frequency.

Thickness (nm)	Freq. (THz)
10	26
20	27.8
50	30
100	31.5
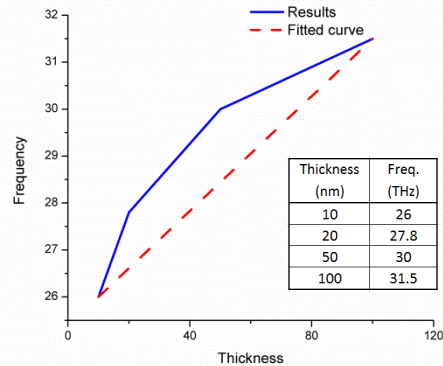
Figure 7. Frequency vs. gold layer thickness.

4. Conclusions

Adding a layer of gold allows the control of resonance frequency of star shaped Ag-ZnO nanostructures which can be used as THz radiation detection and/or as nanoantennas for TB/s communications which is the next step on this research.

Numeric simulation based in FEM Method is helpful to optimize the performance of nanostructures at infrared and visible radiation.

5. References

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6. Acknowledgment